Detection-response task: How intrusive is it?

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Abstract— **The Detection-response task (DRT) is a method for assessing the attentional effects of cognitive load of drivers. Although many studies focusing on the evaluation and the sensitivity of the method have been performed, it is harder to find data on the impact of the method to the driver and his/her driving performance. In this paper, we present a study in which we explore the intrusiveness of the method of all of its versions: visual DRT, tactile DRT, and auditory DRT. We explore possible effects on cognitive distraction, driving performance and secondary task performance (for example operating an in-vehicle device). The results got in the study suggest that DRT does not impose significant additional cognitive load, however it affects driver speed regulations in terms of acceleration deviations, and increases the time need to complete secondary tasks.**

Keywords: detection-response task (DRT), driving performance, cognitive load, attention, *n* – back task, IVIS.

I. INTRODUCTION

The Detection-response task (DRT) is a method for assessing the attentional effects of cognitive load of drivers [1]. It is used to evaluate how use of in-vehicle information and infotainment systems affects drivers' attention. It is based on the performance of a secondary task, where drivers are presented with visual (RDRT) [1], tactile (TDRT) [1] or auditory (ADRT) [2] stimuli and have to respond to it by pressing a button attached to their finger. The method suggests that increased cognitive load would reduce driver's attention to other visual, tactile or auditory information, and thus result into the driver missing and not answering the presented DRT stimuli. With this method, response times and hit rates are observed as indicators of changes in cognitive load and its effect of driver's attention. Response time and hit rates are used as indicators of cognitive load, where longer response times and lower hit rates indicate increase in cognitive load. Mean response time is calculated as the mean of all correctly detected stimuli between 100 and 2500 milliseconds after its triggering. Hits before 100 ms are considered as "early", and hits after 2500 ms as "missed" and should not be included in the mean response time calculations. The mean hit rate is calculated as the ratio of correctly detected stimuli and all stimuli presented (correctly and incorrectly detected stimuli).

Driving is a complex multimodal task, and as such engages and relies on more than one of driver's attentional resources. When the driver uses an in-vehicle information device or any other mobile device, he/she is exposed to dual tasking. This can result in an increase of cognitive load, which can be defined as the load that performing a particular task imposes on the learner's cognitive system [3]. And although the DRT method is used to assess cognitive load of performing a secondary task while driving, it also introduces an additional one. With this study, we want to explore the effect of using this method on driver's cognitive load, driving performance and secondary task performance (use of in-vehicle systems).

II. METHODS

The experiment was conducted in simulated driving environment using a NERVteh driving simulator [4]. Participants drove on a highway, which followed Slovenian traffic rules. Slovenian highway regulations define a maximum allowed speed at 130 km/h, overtaking is always from the left side, the lane furthest on the left is considered as overtaking lane, whereas the rest (most often only one lane) are used for driving.

A. Participants

24 participants (12 female) took part in this experiment. Only participants with a valid driving licence were invited to participate in the study. None of the participants reported any hearing problems, and had normal or corrected to normal vision.

B. Tasks

This study involved three tasks: driving, answering to DRT stimuli, and a performing cognitive task. Each participant performed 8 2-minute-long trials:

- driving
- driving and a cognitive task (n-back task)
- driving and RDRT
- driving and RDRT, and a cognitive task (n-back task)
- driving and TDRT
- driving and TDRT, and a cognitive task (n-back task)
- driving and ADRT
- driving and ADRT, and a cognitive task (n-back task)

DRT stimuli were presented and responses to them were recorded with an Arduino Mega board [5]. Pupil dilation was measured with Tobii Pro Wireless Glasses 2 [11].

1) Primary task: Driving

The primary task was safe driving. Participants drove on a Slovenian highway and were instructed to drive at a constant speed 130 km/h. They were also instructed to use only the driving lane, to do not drive over the speed limit and to don't reduce the instructed speed unless for safety reasons (curvy road, obstacles on the road, etc.).

Driving performance indicators were collected from the automatic logs from the NERVteh driving simulator [4].

2) Secondary task: Detection response task (DRT)

All drivers had to perform 6 trials with DRT (2 with each stimuli modality). Participants were presented with DRT stimuli in randomly chosen 2 to 5 second intervals. With this task, the driver is asked to answer to the presented stimulus by pressing a button against the steering wheel, which is attached on his/her left hand index finger. DRT stimuli were presented and response times were recorded with an Arduino Mega board [5].

In this experiment, three versions of the detection response task are used:

- remote visual DRT (RDRT)
- tactile DRT (TDRT), and
- auditory DRT (ADRT).

The visual and tactile DRT followed the recommended technical specifications for presentation of stimuli, defined in the DRT ISO standard 17488 [1]. For the auditory DRT, we used a 1000 ms long 4000 Hz pure tone signal. The auditory stimuli were presented to the participants at 60 dB SPL through headphones in order to avoid sound travel delays in the response time [6]. The background vehicle sounds were played at 70 dB SPL.

3) Task with secondary priority: n – back task

To increase driver's cognitive load, we used the Delayed Digit recall task, also known as a modified *n* – back task [7]. It requires the driver to respond to stimuli (one digit numbers from 0 to 9) in a specific sequence order (0-back, 1-back, 2-back or 3-back. For example, for 2-back task, drivers have to repeat the number they heard second to last (Table 1). In a NHSA paper by the US Department of Transportation, the 2 – back task level is suggested to be starting point for setting a limit for acceptable amount of cognitive distraction [8]. Therefore, in order to impose the highest acceptable cognitive load, the 2 – back task level was used in this study. The numbers were presented auditory in a randomized order, 5 seconds apart. The participants were asked to repeat the numbers as quickly and as accurately as possible.

Table 1: Consequential order of numbers in a 2 – back task.

	2 - back					
Stimuli	0	4	8	9	4	3
Answer	--	--	0	4	8	9

4) Variables

Level of cognitive load and answering to DRT stimuli (additional task) were defined as independent variables. Cognitive load was manipulated in two levels: without a cognitive task (cognitive load only from driving) and with a cognitive task (2-back task).

Participants also performed trials without and with DRT stimuli. We observed all three types of DRT stimuli modalities: visual, tactile and audio stimuli.

Cognitive load, secondary task performance and driving performance were observed as dependent variables. We observed more than one indicator for most of these variables:

- cognitive load: pupil size,
- secondary task performance: percentage of correctly repeated numbers out of all presented numbers and task completion times (time from presentation of number until the participant answers), and
- driving performance: speed and acceleration average values and standard deviations.

Since we wanted to explore whether answering to DRT stimuli imposes additional cognitive load, we wanted to use another method for assessment of changes in cognitive load. This method had to be a non-invasive psychological measure that does not impose additional task to the driver. Studies have shown that changes in driver's cognitive load can be detected by monitoring driver's pupil dilation [9], which can be done with a low cost or high end eye-tracker [10].

We observed (automated logs of) average speed, acceleration, and standard deviations of speed and acceleration as indicators of driving performance.

Performance rate and task completion times were measured as indicators for secondary task performance. The performance rate is calculated as ratio of the correctly answered stimuli out of all stimuli presented (numbers in the n-back task). Task completion times are defined as the time from the presentation of n-back stimuli until the moment the participant gives a correct answer. Incorrect answers and completion times longer than 5 seconds are considered as missed and excluded from the calculations of this indicator. Participants answered to the stimuli vocally, by repeating the appropriate number.

III. RESULTS

A. Cognitive load

Levene's test did not show homogeneity of variances for average values of the pupil diameters. Due to the large sample of data (more than 2000 samples per trial), Kolmogorov-Smirnov test did not show normal data distribution, $p<0.05$. Although the pupil size increased from trials with only driving (Mdn=3.868) to trials with driving and answering to DRT stimuli (RDRT Mdn=4.020; TDRT Mdn=3.929; ADRT Mdn=4.029), post hoc pair-wise comparisons (Wilcoxon Signed Rank tests with Bonferroni correction) showed that these differences were not significant, p>0.017. These results suggest that answering to DRT stimuli does not impose additional cognitive load to the driver (Figure 1). Similar results were also for the right eye. The pupil diameter increased from trials with only driving (Mdn=3.818) to trials with driving and answering to DRT stimuli (RDRT Mdn=3.934; TDRT Mdn=3.875; ADRT Mdn=3.936), post hoc pair-wise comparisons (Wilcoxon Signed Rank tests with Bonferroni correction) showed that these differences were not significant, p>0.017 (Figure 2).

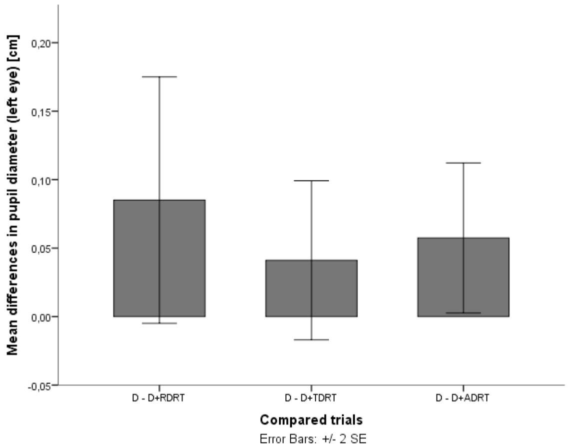

Figure 1. Differences in mean pupil sizes for the left eye for trials without and with DRT stimuli

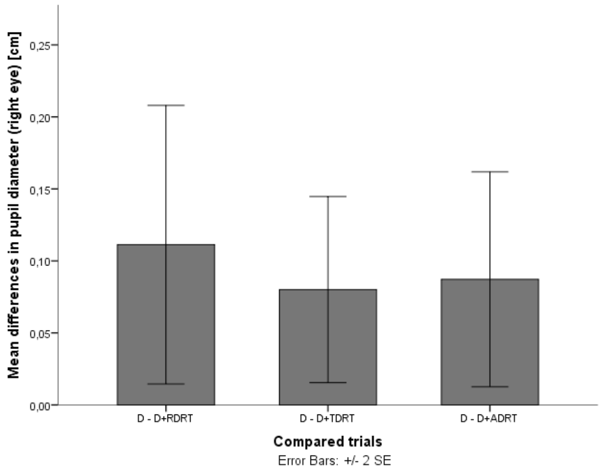

Figure 2. Differences in mean pupil sizes for the right eye for trials without and with DRT stimuli

B. Secondary task performance

Levene's test showed heterogenic variances F(3,90)=3.154, p=0.029. Shapiro-Wilk test did not show normal data distribution p<0.05. The n-back task performance success rate did not differ for from trials with only driving (Mdn=94.4) to trials with driving and answering to DRT stimuli (RDRT Mdn=94.4; TDRT Mdn=88.8; ADRT Mdn=94.4), and post hoc pair-wise comparisons (Wilcoxon Signed Rank tests with Bonferroni correction) showed no significant difference also for TDRT, p>0.017.

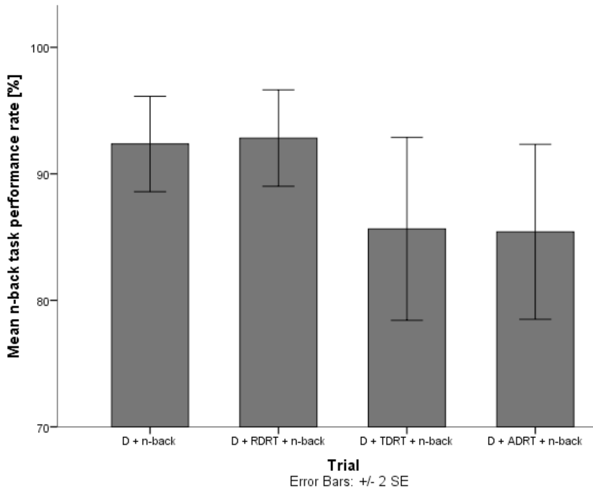

Figure 3. Mean n-back task performance rate for trials without and with DRT stimuli.

Shapiro-Wilk test showed data comes from a normal distribution for task completion times. Levene's test showed homogeneity of variances F(3,92)=0.350, p=0.789. Mauchly's test, $\chi 2$ (5) = 4.508, p = 0.479 did not indicate any violence of sphericity. Tests of within-subjects effects showed that the difference between means was statistically significant: F(3,69) = 5.605, p = 0.02. The mean n-back task completion times increased from M=1.579) to trials with driving and answering to DRT stimuli (RDRT M=1.700; TDRT M=1.693; ADRT M=1.734), as shown in Figure 4.

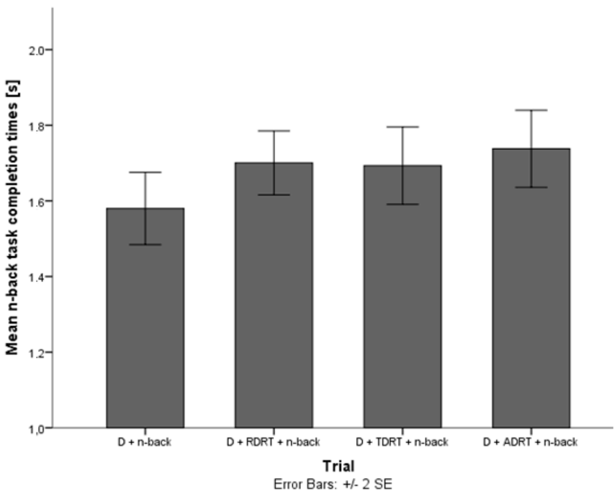

Figure 4. Mean task completion times for trials without and with DRT stimuli.

C. Driving performance

Levene's test showed heterogeneity of variances. Kolmogorov-Smirnov test was used to test distribution normality. It showed the data was not normally distributed, p<0.05.

Post hoc pairwise comparisons (Wilcoxon Signed Ranks tests with Bonferroni correction, p=0.017) showed that the speed standard deviations of mean acceleration were was significantly different for TDRT (p<0.01) and ADRT (p<0.01) compared to only driving, but were not significantly different for trials with RDRT compared to only driving (Figure 5).

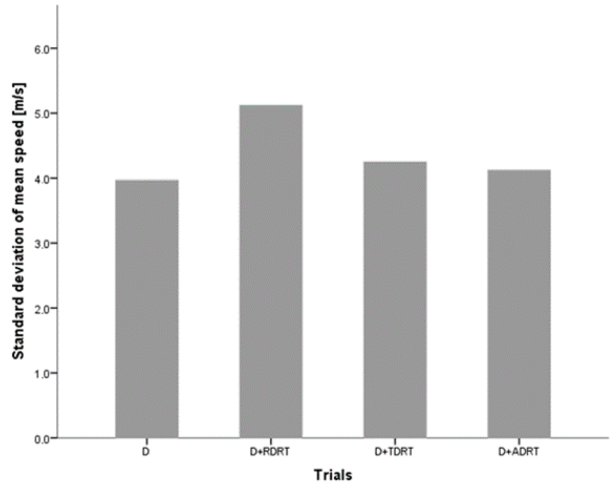

Figure 5. Standard deviation of the mean speed across trials without and with visual, tactile and auditory DRT stimuli

Levene's test of homogeneity of variances showed that variances were not equal, and Kolmogorov-Smirnov test showed that the data was not normally distributed.

Friedman test showed there are significant differences in acceleration between different trials, $\chi2(3) = 1643{,}4$ $p<0.001$.

Post hoc pairwise comparisons (Wilcoxon Signed Ranks tests with Bonferroni correction, p=0.017) showed significant increase in acceleration deviations for trials with DRT stimuli compared to only driving, $p<0.017$ (due to Bonferroni correction), for all three versions of DRT.

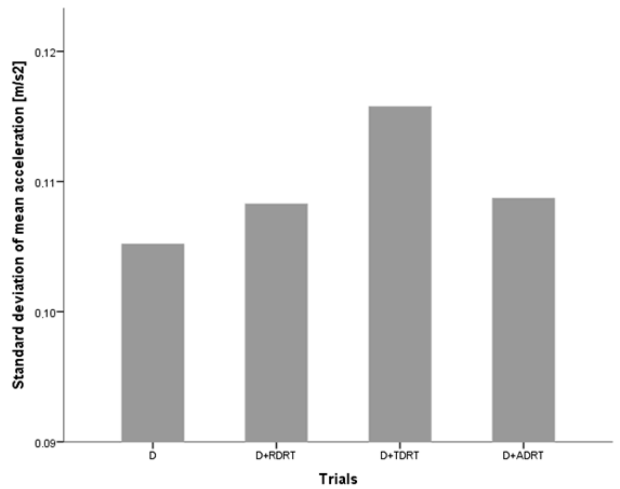

Figure 6. Standard deviation of the mean acceleration deviation across trials without and with visual, tactile and auditory DRT stimuli

I. Dicussion and Conclussion

The driver's pupil size data for trials without the DRT and trials with the DRT did not show significant differences, indicating that answering DRT stimuli does not impose additional cognitive load on the driver.

In the study, participants were asked to drive at a constant speed of 130/km on a simulated highway route with low traffic intensity, which did not require them to overtake any vehicles. Consequently, the average driving speed and average accelerations did not change much during different trials. However, there was an increase in the standard deviation of speed and acceleration for trials with the DRT. This can be interpreted that participants had to put more effort to complete the task of driving at a constant speed.

The performance of the secondary task (i.e. a delayed digit recall task (n-back task)), did not decrease statistically significantly when users were asked to respond to the DRT and drive compared to trials without the DRT and only driving. However, there was a fall in the performance success rate for trials with the TDRT and ADRT compared to only driving. Furthermore, the task completion times for each part of the task (time to repeat the number at the requested order) increased significantly for trials which also included answering DRT stimuli. Since task completion times are often observed as an indicator of a system's usability, researchers should be careful in interpreting this data when evaluating a system using the DRT.

Additionally, from the results on speed and acceleration deviations, researchers should be cautious when performing studies with the DRT in real driving environment, to ensure test driver's safety.

Acknowledgment

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